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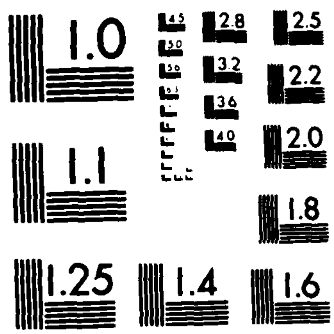

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AGARD ADVISORY REPORT No.188

Future Requirements for Airborne Simulation

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.188

FUTURE REQUIREMENTS FOR AIRBORNE SIMULATION

A Report on the Work of
Sub-Committee 01
of the Flight Mechanics Panel

by

J.Buhrman (retired)
National Aerospace Laboratory (NLR)
The Netherlands

This Advisory Report was prepared at the request of the AGARD Flight Mechanics Panel.

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Published April 1984

ISBN 92-835-1471-8

Set and Printed by Specialised Printing Services Limited
40 Chigwell Lane, Loughton, Essex IG10 3TZ

PREFACE

Airborne and ground-based flight simulation are complementary techniques widely used in aeronautical research and development. The rapid advances in recent years both in the level of sophistication and in the degree of attainable fidelity for modern ground-based flight simulation systems has, however, called into question the future role of in-flight simulators in the research and development processes. The premise that this role may soon disappear has been addressed by a Subcommittee of the AGARD Flight Mechanics Panel. It is concluded that general-purpose airborne simulators and special-purpose research aircraft will continue to serve a useful complementary role to the ground-based simulator through the next generation of aircraft development programmes.

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FUTURE REQUIREMENTS FOR AIRBORNE SIMULATION

1. INTRODUCTION

During its 57th Business Meeting in October 1980 the Flight Mechanics Panel approved the contents of Pilot Paper 134 (Appendix A gives an excerpt) and consequently the establishment of an FMP Subcommittee (SC 01) consisting of the following panel members:

Dr S.R.M.Sinclair (Ca)	Chairman
Mr R.O.Anderson (US)	Member
Mr J.W.Britton (UK)	Member
Mr J.R.Renaudie (Fr)	Member

The activities of the subcommitttee were primarily directed to answering the question: "In view of advances which are being made in the state-of-the-art of ground-based flight simulation technologies, will there continue to be a viable role for airborne flight simulators within the aeronautical research and development processes?"

This report is an effort to review the activities of the subcommittee, to give a critical summary of the results obtained, and to present a few conclusions in answer to the above question.

2. ACTIONS TAKEN BY THE SUBCOMMITTEE

One of the first steps the subcommittee took was the preparation of two questionnaires (Appendix B) and the distribution of these among the institutions which were expected to be able to supply relevant information and opinions. (A list of responding organizations and companies is given in Appendix C.) It can be seen that the majority of the responses came from North America, ten of these being from industry. The much smaller contribution from Europe came mainly from research institutes and only one (explicitly) from industry. This imbalance was one of a number of impediments to formulating firm conclusions: the wide variety of opinions as to the need for in-flight simulators also obscured the field of view of the subcommittee. Nevertheless, with this base of information the subcommittee requested that the author write a brief report summarizing the SC 01 survey and addressing the principal concern of the subcommittee, namely "Is there a future role for airborne simulation in the aeronautical R and D activities of the NATO nations which justifies continued expenditure on new and updated airborne flight simulation facilities?" As further background information the subcommittee recommended studying NASA Technical Memorandum 81156 (V/STOL Flight Simulation, November 1979) prepared by the Ad Hoc Study Group for the Aeronautics Panel of the Aeronautics and Astronautics Coordinating Board (Ref.1).

3. CRITICAL REVIEW OF THE RESPONSES TO THE QUESTIONNAIRES

3.1 General

Since the majority of the responses came from North America and because those responses differed clearly in character from those submitted by European countries, the two groups are first considered separately in Sections 3.2 and 3.3, the areas of concurrence and divergence being dealt with in Section 3.4. (In Appendix D a list is given of airborne flight simulators about which the subcommittee received information. Although many of the respondents supplied detailed information on the characteristics and capabilities of their facilities, the nature and extent of the information varied greatly from case to case; consequently only a very brief description of each facility is given.)

3.2 North America

The list of active airborne flight simulators given in Appendix D includes aircraft operated by four North American organizations: Calspan Corp., NASA Ames, NAE/Canada and Princeton University. It is not surprising that the respondents from these organizations see a clear future for in-flight simulation and that they are convinced that the exclusive use of even the most advanced ground-based simulators is insufficient for research and development purposes. Their strong arguments include:

the "true" environment cannot be simulated on the ground; both motion and visual cues are imperfect in a ground-based facility.

- for the development of very advanced vehicles (e.g. Concorde, Space Shuttle, Relaxed Static Stability aircraft) which deviate markedly from existing aircraft, in-flight simulation is extremely useful, if not a must,
- conclusions drawn from ground-based simulator experiments have proved to be erroneous in a number of cases,
- in a ground-based simulator, in particular when carrying out a low-altitude mission, the pilot operates at a stress level which differs too much from that in actual flight.

Furthermore, a continued need for in-flight simulators is anticipated by Test Pilot Schools for demonstration and training purposes.

On the other hand the responses from the US industry show a more reserved character. There is, nevertheless, a wide variety of opinion in these responses, ranging from "have no such facilities and none planned" to "costs are far outweighed by benefits". Most manufacturers have some experience with the in-flight simulation technique but the fervent faith seems to be lacking and the aspects of costs and budgets show up more regularly than in the responses of the operators.

It may be that a few respondents were not familiar with past uses of variable-stability aircraft, since the results of many programmes were not widely published. On the other hand respondents who have sponsored in-flight simulation programmes have a better understanding of the relevant technical implications and programme costs. This could be an explanation for some of the contradictions in the survey replies.

Three main groups of vehicles for which in-flight simulation has played an important role in the development phase can be distinguished:

A – Conventional Take-Off and Landing (CTOL) fighter aircraft
B – CTOL transport aircraft
C – Vertical or Short Take-Off and Landing (V/STOL) aircraft

GROUP A

The development of the latest series of advanced Air Force and Navy fighter aircraft (F-15 through F-18) has clearly shown the benefits of in-flight simulations. Deficiencies which were not observed or were considered innocuous in the ground-based simulator (in particular PIO tendencies) were disclosed by the in-flight simulation technique.

These experiences have led to the idea of the development of a so-called "Fighter TIFS" (Total In-Flight Simulator). Although it is felt that a requirement for such a research aircraft does exist, it is again cost which hampers a breakthrough with this project. "Fighter TIFS" has not proceeded further than the study phase.

The use made by the USAF of in-flight simulation techniques is reviewed in Reference 2.

GROUP B

When the developments of advanced control and stabilization systems, such as those introduced in modern fighter aircraft during recent years, find their way into (civil) transport aircraft designs it can be expected that in-flight simulation will become a more and more necessary tool for the manufacturers of that category of aircraft. This will be the case in particular when the trend towards Relaxed Static Stability aircraft takes shape and when more sophisticated cockpit controls and dispays are introduced, many of which will have to be evaluated in flight. Approach and landing will be the most demanding flight phases. A continuing need for in-flight simulation facilities or special-purpose research aircraft can therefore be anticipated in the eighties.

GROUP C

A thorough analysis of the in-flight simulation requirements for the development of V/STOL aircraft has already been presented in Reference 1. This report addresses V/STOL aircraft in the development of which the in-flight simulator has played a key role. Since the service life of the available fixed-wing simulators is coming to an end the question arises – what measures can be taken to meet the requirements to be expected in the eighties? To this end the Ad Hoc Study Group, which prepared that report, reviewed the required capabilities of in-flight simulators, the experience with V/STOL in-flight simulators and the candidate options for future programmes.

The conclusions of the report can be summarized briefly as follows. The cost of the development of a completely new research aircraft with all the desirable characteristics is considered to be prohibitive. Therefore, if the US intends to pursue the development of high-performance V/STOL aircraft, interim solutions using the best available research aircraft (X-22A, CH-47B and the YAV-8B) have to be sought. To this end the initiation of relevant studies by NASA and the Navy was recommended.

From the above it may be concluded that requirements are certainly perceived in the US and Canada for in-flight simulation facilities suitable for the development of a variety of aircraft, including unconventional vehicles such as the Space Shuttle. Nevertheless a few critical remarks are in order:

A flight simulator of any kind contains two basic elements: a mathematical model representing the vehicle to be investigated and a system supplying sensory information to the pilot. There is no doubt that the in-flight simulator scores higher than the ground-based simulator as far as the second element is concerned. However, that is not the case for the mathematical model to be implemented since the constraints of the airborne environment still tend to limit computation capabilities and the consequent imperfections in the model can limit the validity of airborne simulation. Clearly, erroneous conclusions can be drawn from the results of in-flight simulations just as surely as from ground-based simulation programmes.

An in-flight simulator will, in general, not meet all the requirements of a particular customer, so that technical and sometimes also financial compromises have to be made in airborne simulation just as in the case of the ground-based simulator.

The structural characteristics of an aircraft to be investigated are not usually simulated in the test aircraft: in particular aero-elastic effects can have an unfavourable influence on the "fidelity" of the simulator.

Most manufacturers have complete control over the ground-simulator(s) they use for the development of their designs. This is less likely to be the case for an airborne simulation facility, and manufacturers will be reluctant to reveal too many details of their designs to the agency running the simulator. (The details required for a high-fidelity simulation go far beyond the information which the designer must provide, for example, to a wind-tunnel operator.)

Notwithstanding these drawbacks there is a consensus within the US *armed forces* and *manufacturers* involved in military projects that there is a need for in-flight simulation. The requirements of the manufacturers of civil aircraft for in-flight simulation facilities are less well defined, but it is anticipated that interest will increase gradually during the eighties. The technology needed to meet these requirements is available, but the development of new aircraft for the in-flight simulation role or the re-equipping of existing aircraft for this purpose will very probably be hampered by budgetary constraints.

3.3 Europe

While the subcommittee received a substantial number of responses from aircraft manufacturers in the US, it did not have the benefit of official statements from the European industries with the exception of British Aerospace in the UK. It might therefore be concluded that the industrial interests are not very keen. Most of the responses came from research institutes, while the test pilot schools in England and France stated the need for a variable-stability aircraft as a "flight mechanics demonstrator".

The most positive comments came from the German Aerospace Research and Development Establishment (DFVLR). Since 1972, DFVLR has been active in in-flight simulation using the HFB-320, which is now being decommissioned and which will be replaced by a new general purpose simulator designated ATTAS (see Appendix D). Furthermore, the DFVLR helicopter BO-105 S3 will be modified as a variable-stability rotorcraft. The German aerospace industry also sees a clear need for a general-purpose in-flight simulator in the future.

The response from France, where the variable stability Falcon (Mystère 20) is under construction, was more reserved: in-flight simulation can be considered useful, but the high costs prevent aircraft manufacturers from building such a highly sophisticated aircraft system for their own needs. A national in-flight simulator can possibly meet the requirements of all manufacturers in that country.

In the UK, the RAE cannot see a clear role or need for a general-purpose in-flight simulator. This view is shared by British Aerospace. It is reasoned that the available UK ground-based simulators together with the research aircraft (for example Jaguar, BAC 1-11 and two seat Harrier) form a complementary set of tools to meet almost all demands.

The smaller nations have exhibited an interest in airborne flight simulation, but lack of funds prevents the procurement of the required facilities. Nevertheless, NLR in the Netherlands executed a research programme in the field of handling qualities criteria for civil aircraft using the USAF/Calspan TIFS. This is a typical example of the way in which both research and development demands for in-flight simulation will have to be met. Another example of such an in-flight simulation programme is the co-operation between ONERA and Princeton University in a study of direct side-force control using the Princeton VRA.

Thus the question arises whether the development of a European general purpose in-flight simulator, which could be operated at the request of any interested aircraft manufacturer or research institute, would be a practical development. It is felt, however, that, even though the structure to promote such an international tool does exist with groups such as GARTEUR associating UK, Germany, the Netherlands and France for the period of the eighties the realization of such a facility will be very difficult for the following reasons:

national industries will in general be willing to reveal their almost complete design to the agency managing the facility *only* in the case of a joint (multinational) project,

the high costs of such a simulator will prove to be a serious impediment to such a venture,

- defining the concept "general purpose simulator" to satisfy the demands of all future customers will be a very difficult exercise,
- a cost-effective operation of the simulator seems problematic.

The most realistic expectation for in-flight simulation in Europe can therefore be summarized as follows: the needs for applying this technique do exist in Europe as well as in the US, albeit on a smaller scale. These specific needs will be met by means of available (research) aircraft, which will have to be adapted to the goals pursued. Only the projects ATTAS and Falcon can be considered as general-purpose in-flight simulators. Further use of "foreign" in-flight simulator aircraft can be expected mainly for basic investigations by research institutes.

3.4 Comparison of the Situation in North America and in Europe

In North America the in-flight simulation technique has been applied to a considerably larger extent than in Europe and the number of European aircraft equipped as in-flight simulators is relatively small. Quite a few countries have no such aircraft at all. This fact does not imply that the benefits of the technique are not recognized by these countries recognition is reflected in the use from time to time of American facilities by European organizations but the lag in development is unmistakable. It is believed that this lag is due to the combination of the following reasons:

- equipping a national aircraft as an in-flight simulator is a costly enterprise,
- it is not clear that such a facility can be used in a cost-effective way,
- the position of most European aircraft companies is that of interested observers and not that of strong supporters,
- potential customers including the armed forces are inclined to think of ad-hoc solutions when the need arises.

Some of these reasons apply also to the United States to a lesser extent because in that nation

- the number of advanced air vehicle projects is considerably higher,
- there are no national boundaries which have to be overcome before useful co-operation can be effected,
- the interest and support of the armed forces is definitely stronger,
- available budgets for in-flight simulation programmes, although they are also under close scrutiny, are, on average, higher.

4. SUMMARIZING CONCLUSIONS

From the foregoing, the following conclusions can be drawn:

(1) Airborne simulation and ground-based simulation are complementary techniques.

(2) The question posed by the subcommittee (Section 1) can be answered in the affirmative: there will continue to be a viable role for airborne simulation since new technical problems – some of which can best be solved in the real flight environment (e.g., using prototype, in-flight simulator or special purpose research aircraft) – will continue to arise.

(3) Internationally sponsored in-flight simulation facilities are worthy of consideration.

(4) Many potentially-interested customers for general-purpose airborne simulators are not convinced of the value of the technique, preferring special-purpose solutions to meet their needs.

(5) Most of the requirements identified for airborne simulation emerge from the development of conventional fighter aircraft and V/STOL aircraft. There is a more reserved attitude among the manufacturers of conventional civil aircraft.

(6) As with all new aeronautical facilities, high costs will hamper approval for and development of new general-purpose in-flight simulators.

5. RECOMMENDATION

Most of the information collected by the subcommittee refers to in-flight simulation achievements in the past and to facilities which are in current use. On the other hand Reference 1 makes a serious effort to evaluate future needs. Further studies of this type should be encouraged; however such studies require an insight into the nature and extent of future aerospace projects for which the technique will have to be applied. Such a survey should cover the period of the next 5 to 6 years.

6. REFERENCES

1. *V/STOL Flight Simulation*, NASA Technical Memorandum 81156, November 1979.

2. Markman, S.R. *The United States Air Force and the Use of In-Flight Simulation*, 12th Annual Symposium of the Society of Flight Test Engineers, September 16–18, 1981, Dayton, Ohio.

APPENDIX A

EXCERPT FROM THE FLIGHT MECHANICS PANEL PILOT PAPER No.134 ON FUTURE REQUIREMENTS FOR AIRBORNE SIMULATION

INTRODUCTION

Simulation in the most general sense of the term has always been part of engineering design and system development but it has found its highest engineering expression in the modern aircraft flight simulator. Within the aeronautical community the word simulation has in fact become virtually synonymous with the reproduction of the cockpit flight environment in a ground-based flight simulation facility. As this discipline has matured and assimilated the advances in digital processor and electronic display technologies, ground-based flight simulation has expanded its legitimate domain of investigation and application both as a research and development tool and as a training aid. On the training side, the aviation regulatory agencies are evaluating the concept of "total simulation" - 100% type-qualification training for commercial pilots using, exclusively, ground-based training simulators, with only a routine line check ride in the aircraft. The importance of simulators in aeronautical R and D on the other hand is supported by a vast amount of technical literature.

An aura of authority has grown up around the laboratory flight simulator and consequently the results from experiments using these simulators are often accepted uncritically. Nevertheless ground-based flight simulation does have significant limitations and although the boundaries for application are system-dependent and are not precisely defined, the bases for the limitations are reasonably well understood. They are, of course, related to the incomplete - and sometimes conflicting - nature of visual and other motion cues which are presented to the evaluating pilot. Under such circumstances the performance and workload of the pilot may depend heavily upon what would appear to be only subtle differences between the simulation and real-world environments.

Airborne simulators and variable-stability aircraft have played an important role in aeronautical research and development by filling a gap between the laboratory simulator and the flight test vehicle or prototype. Whereas the laboratory simulator is limited in its ability to reproduce the real-world environment at the pilot's station, the airborne or in-flight simulator is intrinsically capable of providing the proper environment by immersing the pilot in a real flight situation; and limitations which arise are more often related to the simulator vehicle's controllability and the on-board computation (modelling) capacity. However, new engine and control system technologies and distributed microprocessor-based computing systems can significantly advance the state-of-the-art in airborne simulation. These airborne facilities can in fact benefit to an even greater degree than laboratory simulators from the miniaturization of modern electronic systems and improvements in computing system speed and data storage capacities. Nevertheless, in the last decade when large investments were made in ground-based flight-simulation hardware, a parallel upgrading of airborne simulators was not undertaken. Some older simulators were decommissioned and several new, special-purpose airborne facilities appeared, but the general-purpose in-flight simulators which are in service today are based on relatively old computing systems and aircraft.

OBJECTIVE

The objective of the subcommittee's work will be to answer the question:

In view of advances which are being made in the state-of-the-art of ground-based flight simulation technologies, will there continue to be a viable role for airborne flight simulators within the aeronautical research and development processes?

In answering this question it must be understood that major investments in new simulators and simulation systems will be required to support any substantial airborne simulation capability through the next decade.

TASKS FOR THE SUBCOMMITTEE

The work of the subcommittee will include the following:

(a) taking an up-to-date inventory of airborne simulators and variable stability aircraft within the NATO nations. This task should include documentation of the simulation envelope of each facility and a detailed summary of the characteristics of on-board systems (computing, display, guidance systems. . .).

(b) summarizing the plans of each centre-of-expertise which operates one of these aircraft to update, replace or decommission the facility.

(c) listing recently completed and planned programmes for each of the simulators or variable stability aircraft with a brief description of the nature of the simulation task in each case. The intent here is to document the exclusive domain of the airborne simulator in aeronautical research and development.

(d) examining critically the contention that the complete airborne environment is, and will continue to be, essential for investigations involving some combinations of aircraft characteristics and flight tasks if reliable answers are to be drawn from simulation. In performing this task the subcommittee should seek the opinions and advice of a broad cross-section of the R and D simulation user community as well as those of simulation specialists. Projected requirements for airborne simulation should be identified and simulated performance criteria developed which will accommodate the requirements.

BACKGROUND MATERIAL

In November 1979 an Ad Hoc Study Group for the Aeronautics Panel of the Aeronautics and Astronautics Coordinating Board published a report on future requirements for in-flight simulation facilities to support the development of V/STOL aircraft. Although this study focussed upon V/STOL requirements and considered almost exclusively the US requirements and US facilities, the data collected in Reference 1 and the Study Group's conclusions provide valuable information for the subcommittee's work.

REFERENCE

1. *V/STOL Flight Simulation*, NASA Technical Memorandum 81156, November 1979.

Prepared: **Dr S.R.M.Sinclair**
Date: **October 1980**

APPENDIX B

QUESTIONNAIRES

(a) A Survey of Simulator Operators

1. Please provide a detailed description of the variable stability aircraft* which are operated by your Laboratory or Company. As a guide in presenting this information, the following topics are suggested:

   (a) type of aircraft from which simulator has been developed and types of aircraft which can be simulated

   (b) speed range of the simulator when operating in the variable stability and control (VSC) mode

   (c) thrust/weight ratio in representative configurations

   (d) control power levels available at typical operating points in the VSC mode

   (e) number of degrees of freedom which are independently controllable by the VSC system, and the authority and bandwidth of each control channel

   (f) method of implementing VSC system

   (g) computing capacity available for "modelling" (indicating simulation techniques used and degree of complexity of typical simulation mode)

   (h) evaluation-cockpit systems including --
      (i) control force "feel" system
      (ii) controller configurations
      (iii) instrument presentations and displays

   (i) description of on-board guidance and navigation systems which have information displayed at evaluation pilot's station

   (j) motion sensing systems

   (k) data recording, telemetering and data processing capabilities

   (l) planned improvements to the simulator or simulation systems

   (m) expected service life of facility.

2. Please provide a *brief* description of some recent flight programmes which have been conducted using these facilities. Examples of correlation between simulation results and the flight system or prototype test results are of particular interest.

3. Does your organization plan to purchase or develop a new variable-stability aircraft or airborne flight simulator? (If so, please describe *briefly* the planned capabilities of this new facility and the role which it is intended to fill).

4. In view of the advances which are being made in the state-of-the-art of ground-based flight simulation technologies, will there continue to be a viable role for airborne simulation in the aeronautical research and development processes? If so, what are the major areas of R and D which, in your opinion, will present requirements for airborne simulation?

5. Do you perform research in one or more of the following areas? Please indicate approximate percentages (total amount = 100).

   (a) Handling Qualities

   (b) Display Development

   (c) Flight Characteristics

   (d) Specialized Demonstration, Instruction

   (e) Flight Controls (include fire control and propulsion control, integrated systems and controllers)

   (f) Interactive Control/Display

   (g) Other (please specify)

*The survey is intended to cover all aircraft which have significant variable stability and control capabilities. No attempt is made here to delimit or distinguish among the terms "airborne flight simulator", "in-flight simulator" or "variable stability aircraft".

(b) A Survey of Simulator Users

1. In view of the advances which are being made in the state-of-the-art of ground-based flight simulation technologies, will there continue to be a viable role for airborne simulation in the aeronautical research and development processes? If so, what are the major areas of R and D which, in your opinion, will present requirements for airborne simulation?

2. Please provide a *brief* description of recent flight simulation programmes which have been conducted by or for your organization. Examples of correlation between simulation results and the flight system or prototype test results are of particular interest.

3. For 1 and 2 above, please categorize as below:

   (a) Handling Qualities
   (b) Display Development
   (c) Flight Controls and Controllers
   (d) Integrated Control Systems, e.g.: Fire/Flight, Flight/Propulsion, Fire/Flight/Propulsion
   (e) Control/Display interactive
   (f) Flight Characteristics
   (g) Specialized Demonstration, Instruction
   (h) Other (please specify)

APPENDIX C

LIST OF RESPONDING ORGANIZATIONS AND COMPANIES

North America

Research Corporation/University	*Government*	*Industry*
Calspan	US Navy (NASC)	Boeing (Military)
Princeton	US Army (AVRADCOM)	Cessna
STI	US Air Force (AFFDL)	Fairchild
	NASA (Ames, Langley, Dryden)	General Dynamics
	NAE	Hughes
		Lockheed
		McDonnell Douglas
		North American
		Northrop
		Sikorsky

Europe

Research Corporation/University	*Government*	*Industry*
	ETPS	British Aerospace
	NLR	
	RAE	
	DFVLR	
	CEV	

APPENDIX D

LIST OF AIRBORNE FLIGHT SIMULATORS IN NORTH AMERICA AND EUROPE

Country	Aircraft (type and appr. mass)	Manufacturer	Speed range (kts)	Degrees of freedom	Remarks
USA	C-131 H "TIFS" (twin-engined transport; 23000 kg)	GD (Convair)	115-295	6 (full authority within hinge moments)	TIFS (= Total-In-Flight-Simulator) was the "workhorse" in many research programs; operator: Calspan
USA	NT-33A (fighter aircraft; 5400 kg)	Lockheed	120-375	3 (rotations, full authority within hinge moments)	Used by GD prior to YF-16 first flight (side stick force controller); also in use by both Test Pilot Schools for instruction and training; operator: Calspan
USA	X-22A (4-engined V/STOL (research) aircraft with 4 ducted propellers; 8000 kg)	Bell	−30-150	4 (full authority within hinge moments; thrust)	T/W=1.35; used for well over ten years extensively in several programs (take-off, landing and transition); now probably near end of service life; operator: Calspan
USA	Learjet (General Aviation aircraft; 6000 kg)	Gates Learjet Corporation	100-325	3 (full authority within hinge moments)	Aircraft will take over the role of the B-26 as a training tool for the Test Pilot Training Schools; operator: Calspan
USA	UH-1H (helicopter; 4300 kg)	Bell	0-100	4	Research emphasis on basic flying qualities for low-altitude maneuvring tasks; see also 205 A-1 (NAE/Canada) and Ref. 1; operator: NASA/Ames
USA	CH-47B (twin-engined tandem rotor helicopter; 17.500 kg)	Boeing Vertol	0-160	4	Research on controls/displays for decelerating approaches and hover; good simulation of pitch responses for hingeless rotors is possible; T/W = 1.5 (see also Ref.1); operator: NASA/Ames
USA	QSRA (powered-lift STOL aircraft; 22.500 kg)	De Havilland/ NASA/Boeing	60-160	5	The QSRA (Quiet Short-Haul Research Aircraft) has four turbofan engines on upper wing providing added lift; operator: NASA/Ames
USA	Navion VRA (Variable Response Aircraft; 1500kg)	North American Aviation	75-105 (normal operating speeds)	6 (side force panels provide 0.5g at 105 kts)	The aircraft is upgraded by installation of 285 hp engine; operator: Princeton
USA	Navion ARA (Avionics Research Aircraft; 1500 kg)	North American Aviation	75-105 (normal operating speeds)	5 (no side-force control)	The aircraft is, like the VRA, equipped with a 285 hp engine; Princeton does not foresee the need to improve performance or to expand flight envelopes of either VRA or ARA; operator: Princeton
Canada	205 A-1 (15-seat helicopter; 4300 kg)	Bell	From hover to 100	4	Used for simulation of various helicopters, VTOL- and STOL-aircraft. Research emphasis on general handling qualities, advanced control/display systems; operator: NAE
Germany	HFB-320 (Twin engined, swept-forward wing executive aircraft; 8500 kg)	MBB-UT	140-320	5 (flap and/or spoiler DLC, no side-force control)	Digital fly-by-wire in-flight simulator, several research programs in flight path control and reduced/negative stability since 1972, to be replaced by VFW 614 ATTAS; operator: DFVLR
Germany	VFW 614 ATTAS (Twin engined transport aircraft; 19.000 kg)	VFW/MBB-UT	120-380	5 (no side-force control) 6 (panned)	ATTAS (Advanced Technology Testing Aircraft System). Digital fly-by-wire/light in-flight simulator. Available in 1985; operator: DFVLR
Germany	BO 105 ATTHES (Twin-engined utility helicopter; 2300 kg)	MBB-UD	−35-120	4	ATTHES (Advanced Technology Testing Helicopter System). Digital fly-by-wire variable stability helicopter. Available in 1983; operator: DFVLR
France	FALCON (Mystère XX; twin-turbofan executive transport; 13.000 kg)	AMD-BA	90-450	6 (in future)	
UK	Bassett VSS aircraft (twin-engined light transport aircraft; 3200 kg)	Beagle Aircraft	100-155 (usable range)	3 (rotations)	Used by the Empire Test Pilots' School (Boscombe Down) as a variable-stability aircraft for instructional purposes; aircraft will be at end of service life in 1983-84; a potential successor is a (VVS) Hawk aircraft (BAe); operator: ETPS
UK	Jaguar T2 (Fighter Trainer Aircraft)	British Aerospace	120-300	4 (full authority within hinge moments; thrust)	Digital fly-by-wire research aircraft — main emphasis on flying qualities, ACT, stability margin, system architecture, etc.; operator: BAe
UK	BAC 1-11 (twin jet medium transport aircraft)	British Aerospace	100-450	3 (limited authority, pitch, heave thrust)	Civil Avionics Research Aircraft — main emphasis on Flight Management, Cockpit Displays, Navigation; some emphasis on advanced control techniques; operator: RAE
UK	Harrier T2 (two seat VSTOL Fighter Aircraft)	British Aerospace	−30-500	5 (limited authority at present, full authority in future)	VSTOL/STOVL Research Aircraft — main emphasis is on Advanced Control and Displays for this class of aircraft; operator: RAE

N.B. The UK Research Aircraft (Jaguar, BAC 1-11 and two seat Harrier) in the above list are not considered as general purpose in-flight simulators, but rather as versatile and complementary tools to the available ground based simulators. In the context of the Harrier aircraft the TAV-8A and YAV-8B can be mentioned: these aircraft could have substantial in-flight simulator capability, although both have their limitations (see further Ref.1).

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-188	ISBN 92-835-1471-8	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title FUTURE REQUIREMENTS FOR AIRBORNE SIMULATION

7. Presented at

8. Author(s)/Editor(s)	9. Date
J.Buhrman (retired)	April 1984

10. Author's/Editor's Address	11. Pages
National Aerospace Laboratory (NLR) The Netherlands	18

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications

13. Keywords/Descriptors

Flight simulators
Airborne equipment
Research aircraft

14. Abstract

Airborne and ground-based flight simulation are complementary techniques widely used in aeronautical research and development. The rapid advances in recent years both in the level of sophistication and in the degree of attainable fidelity for modern ground-based flight simulation systems has, however, called into question the future role of in-flight simulators in the research and development processes. The premise that this role may soon disappear has been addressed by a Subcommittee of the AGARD Flight Mechanics Panel. It is concluded that general purpose airborne simulators and special purpose research aircraft will continue to serve a useful complementary role to the ground-based simulator through the next generation of aircraft development programmes.

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